# Opportunities & challenges for the design of metalenses and metasurfaces.
# A pragmatic and case based overview

EPIC Online Technology Meeting on Metamaterials and Metalenses
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# Bottlenecks in meta-surface design

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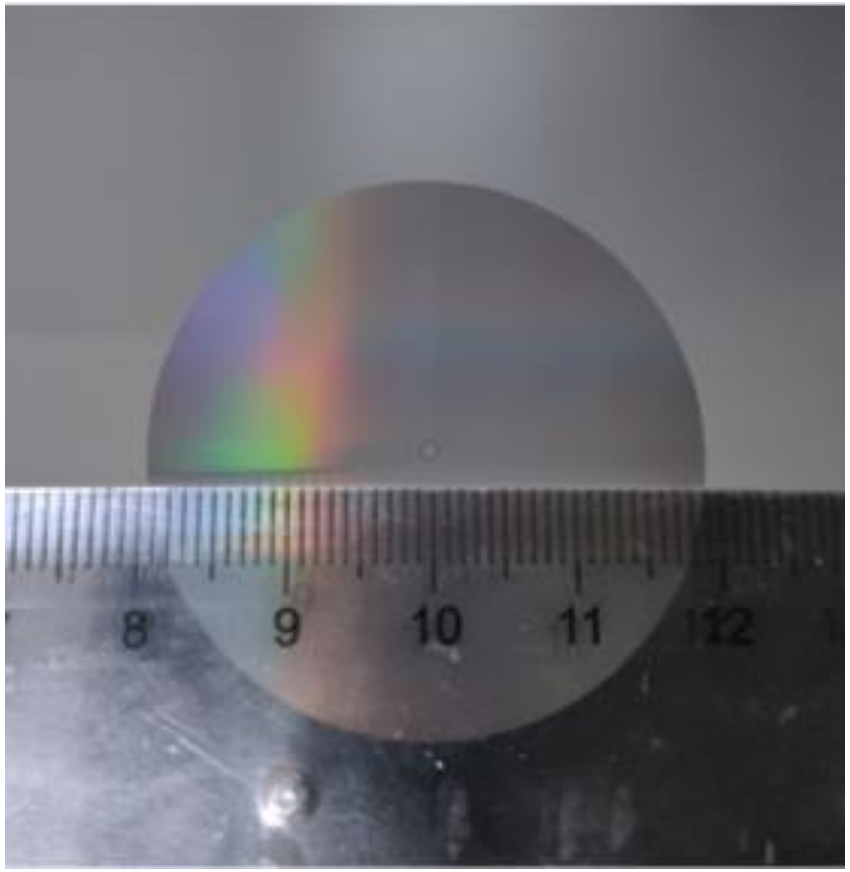
- Make design fast, integrated and reliable
- **Integration** to system level
  - Link from wave to ray scale not well developed
  - System does not take full use of meta-surface possibilities
  - Current models ignore higher order effects
- **Fast Large Area** Design:
  - Full wave algorithms scale poorly
  - Design is slow and area is limited
  - Multi-scale methods increase the limit but require approximation
  - Design iterations require specialists and lots of time
- **Design for Manufacture** is in embryonic stage
  - Most designs are nominal
  - Tools and methods for robust design are needed




40mm diameter metalens

# Meta-optics project flow

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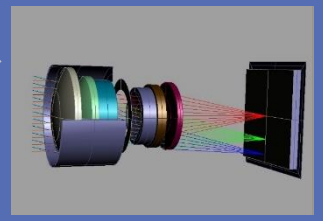
PlanOpSim Support solution

PlanOpSim Software solution

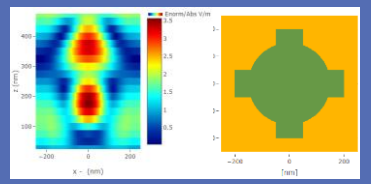
META CELL | META COMPONENT | LIBRARY | JOB OVERVIEW

**Concept**
- Feasibility
- Specs

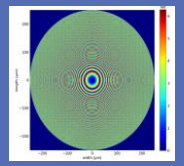
**System model**
- Ray tracing



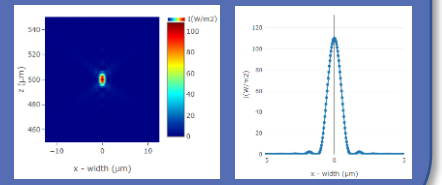
**Nanostructure**
- Full wave RCWA
- Structure library



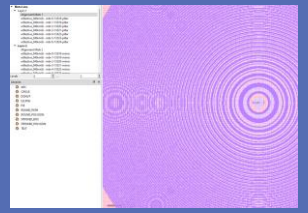
**Component design**
- Propagation
- Wavefront design



**Validation**
- Propagation
- Non-idealities



**Fabrication**
- gds export



REPORT

MASK

# System integration

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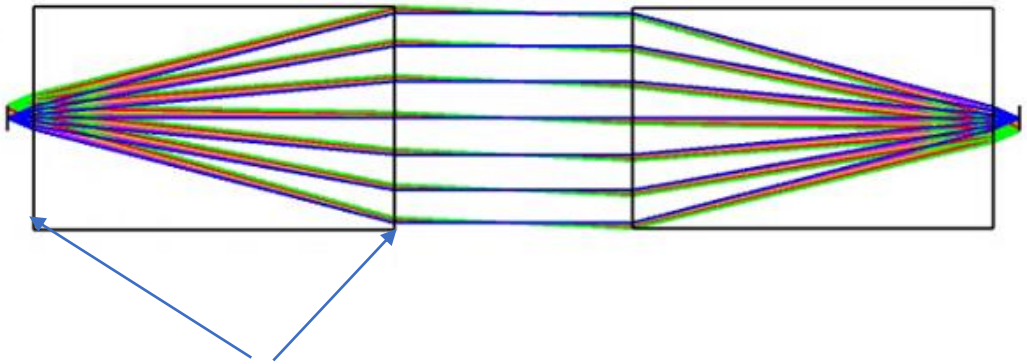
- Ray tracing system design
  - Idealized meta-surface
- Meta-surfaces informed system design
  - Dispersion and polarization control
  - Time band width limits
  - Higher order diffraction
- Cascaded to co-optimized design

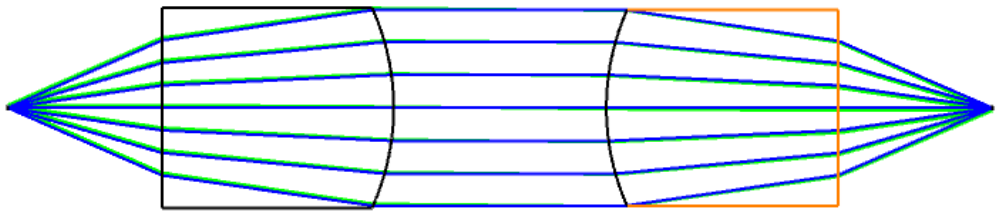
**Classic Fiber coupler**

**Meta-system**

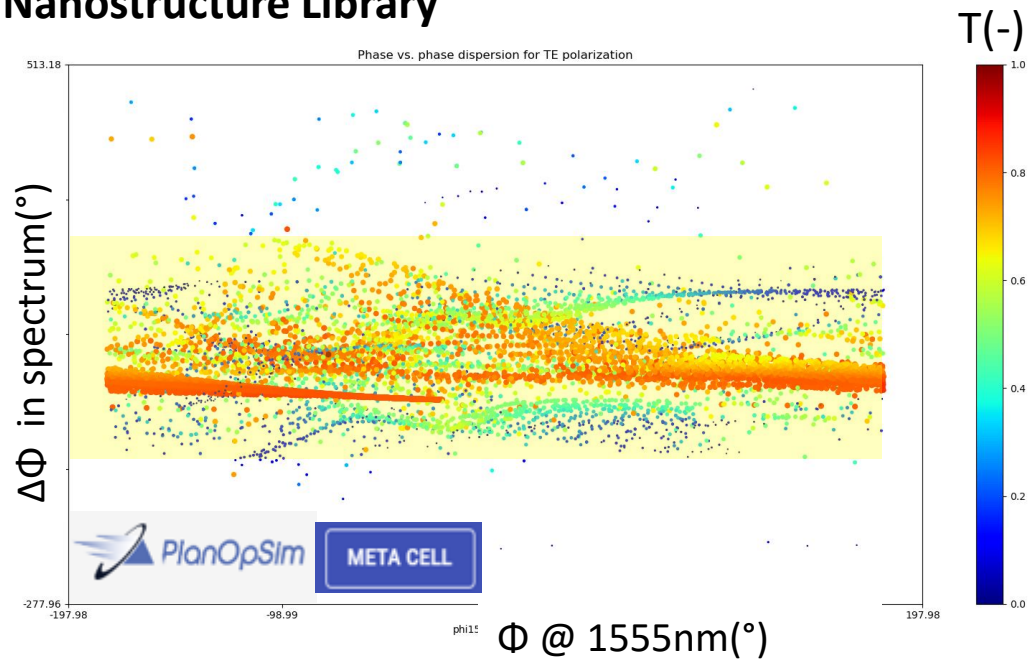


Meta-surface spheric

**Hybrid**



**Nanostructure Library**



# Sample results

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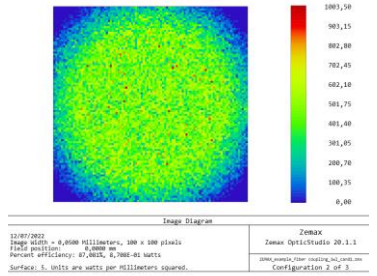
- Meta system
  - 30x smaller
  - 27% fewer losses
- Coupled design 100% necessary
- Nano informs system design
- System design determines structure & components

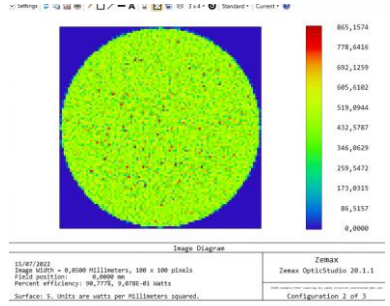
Benchmark design

Dispersion engineered

1530nm

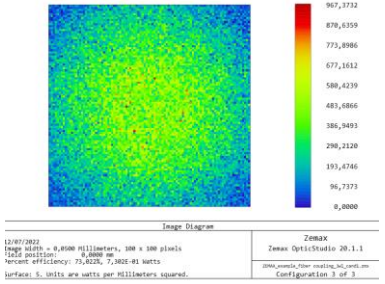


87%

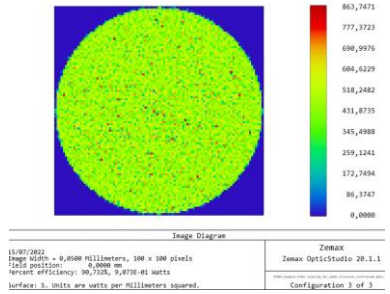


91%

1625nm



73%



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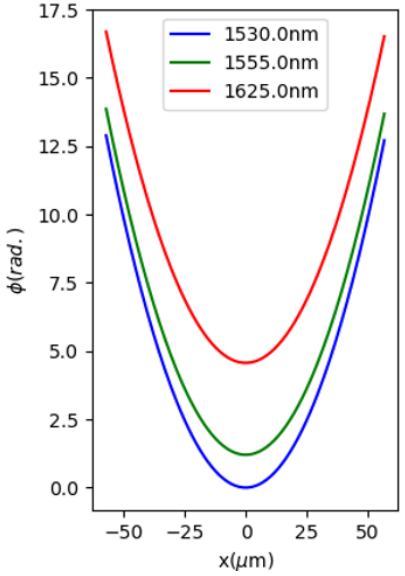


| Case | Avg . Coupling loss | Diameter | System length | Volume |
|---|---|---|---|---|
| Benchmark | -0,57dB | 1,2 mm | 7,6 mm | 34,4 $mm^3$ |
| Spheric + metalens | -0,45dB | 1,8mm | 8,9 mm | 90 $mm^3$ |
| 2 metalens (single wavelength) | -0,79dB | 0,43mm | 1,96mm | 1,1 $mm^3$ |
| **2 metalens (dispersion engineered)** | **-0,42dB** | 0,43mm | 1,96mm | **1,1 $mm^3$** |

# High speed large area design

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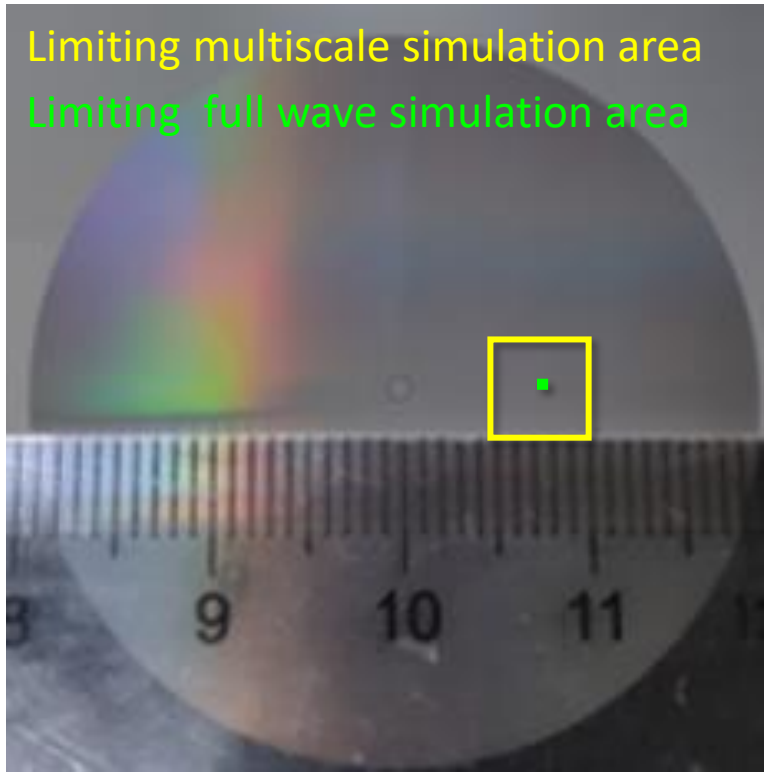
- A 40mm lens is 500 000x larger than full wave simulation areas
  - Using multi-scale simulation the factor is 50-200
- Most time consuming aspect of design is the simulation of nano-structures
  - Typical: several **10 000s of structures**
  - Parametrized or free-shape structures
- Design contains a solver and an optimization loop
  - **Time spent = #calls x loop time**
  - Loop time determined by EM solver
- Two approaches to speed up:
  - Reduce #calls: smartest optimization alogrithm
  - Reduce loop time: fastest solver




Large metalens

# High speed large area design

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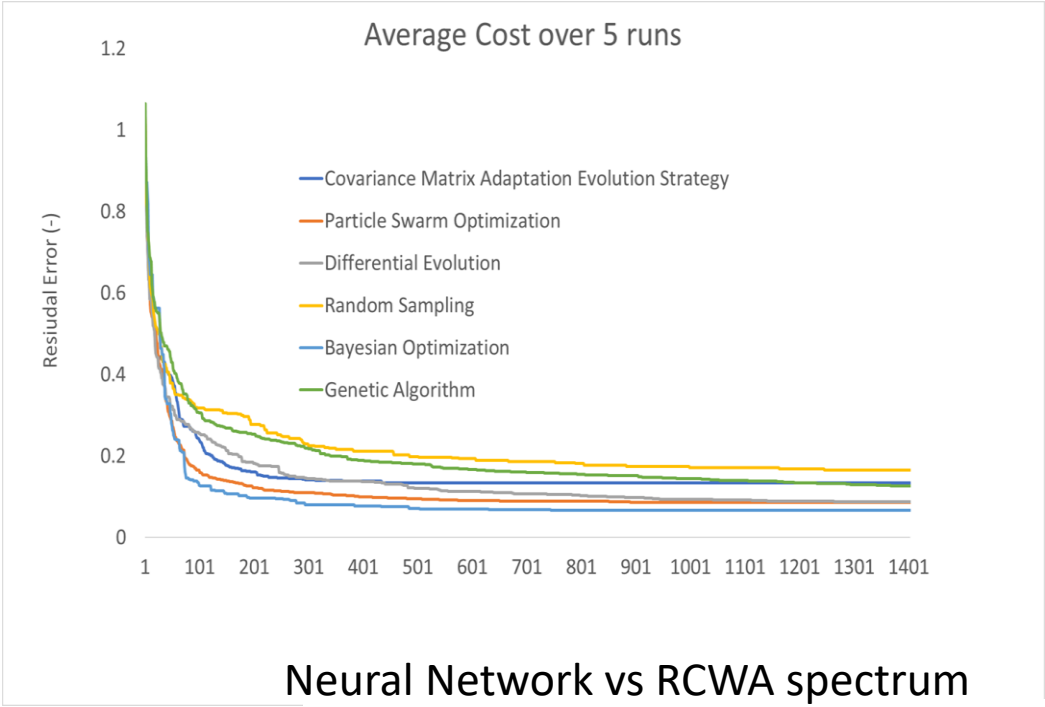
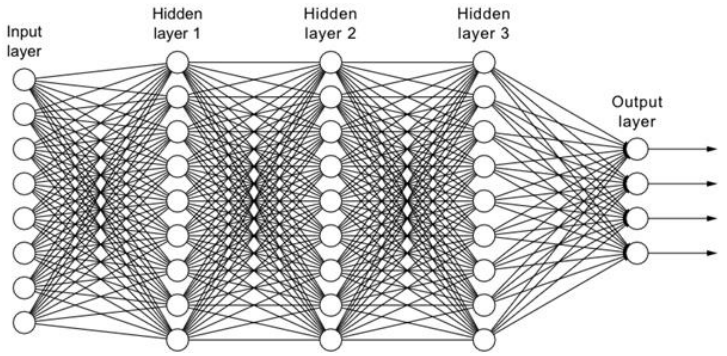
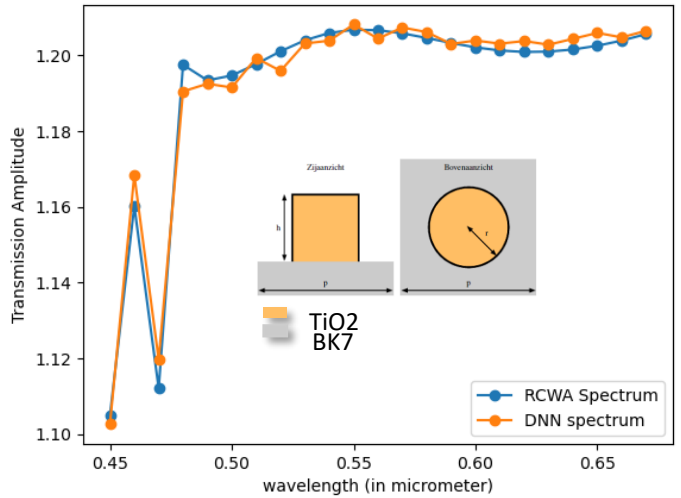
- Inverse design:
  - Various optimization algorithms
- Surrogate Solver
  - Pre-trained NN replaces full wave
- Combined optimization + network
- Requirement:
  - Large **training set generated** by classical **full wave**
  - Specific configurations




Neural Network vs RCWA spectrum



# High speed large area design

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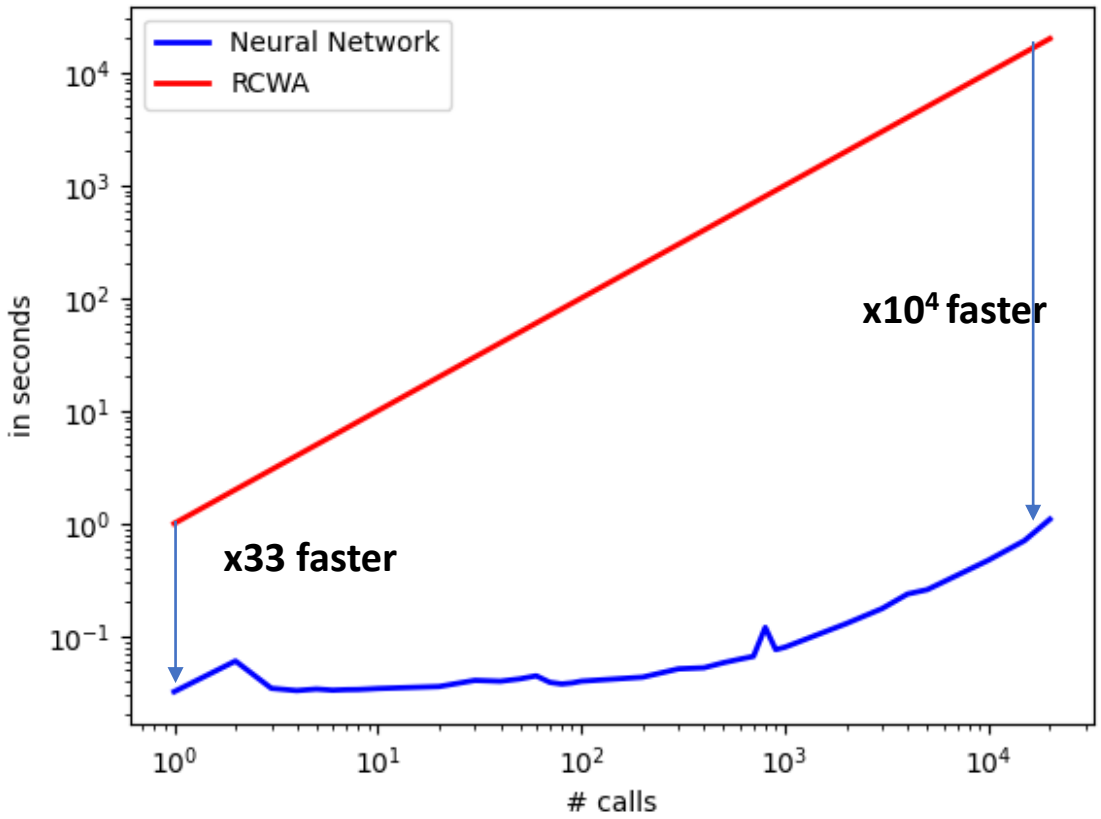
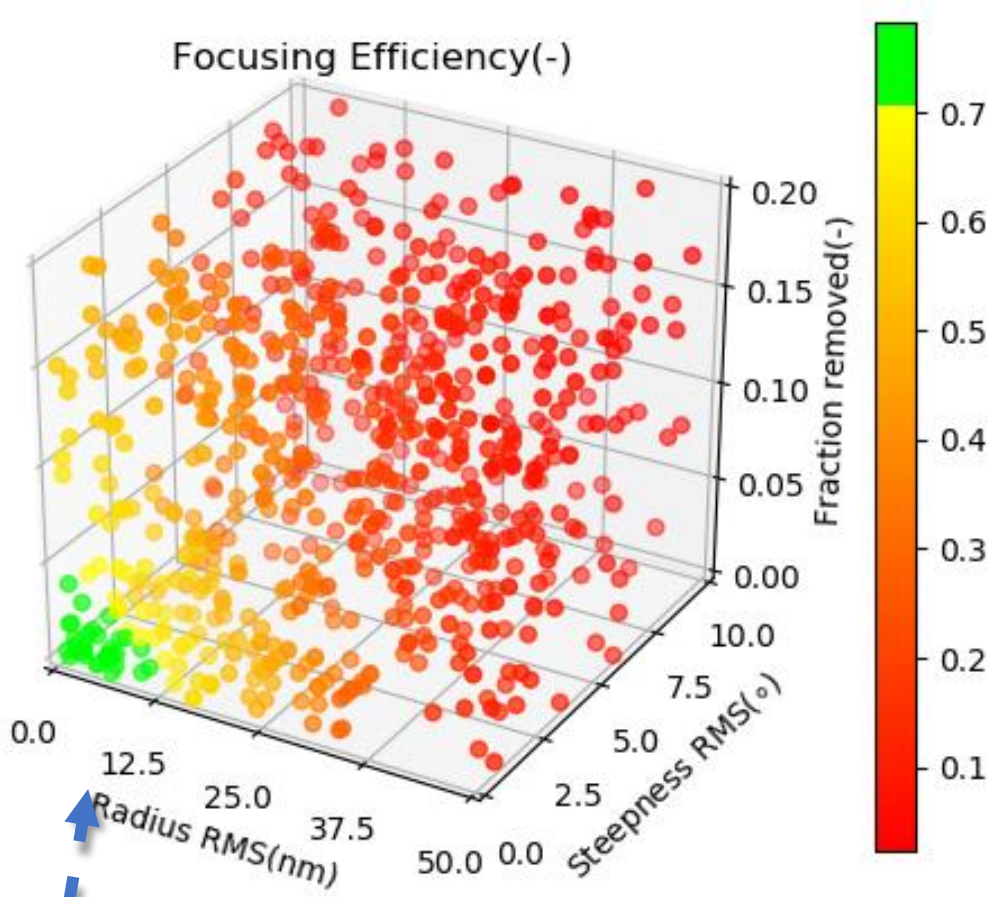
- **Surrogate solver** and **optimization methods** can **speed up** meta-atom design **up to 500 fold**
- **PSO, Bayesian** and **adjoint** method are **most performant optimization** algorithms
- **Training takes more time** than a **classical design**
- Future work:
  - Wide applicapility
  - Larger area

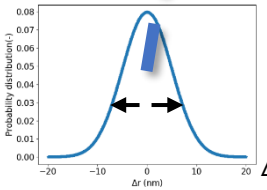
| | Total calculation time | Acceleration factor |
|---|---|---|
| **Brute force sweep** | **19.55hr** | 1 (baseline) |
| **Inverse design** | 8.9hrs | 2 |
| **Neural network** | 0.53hrs | 37 |
| **Genetic Algorithm + Neural netowrk** | **0,04hrs (3mins)** | **488** |

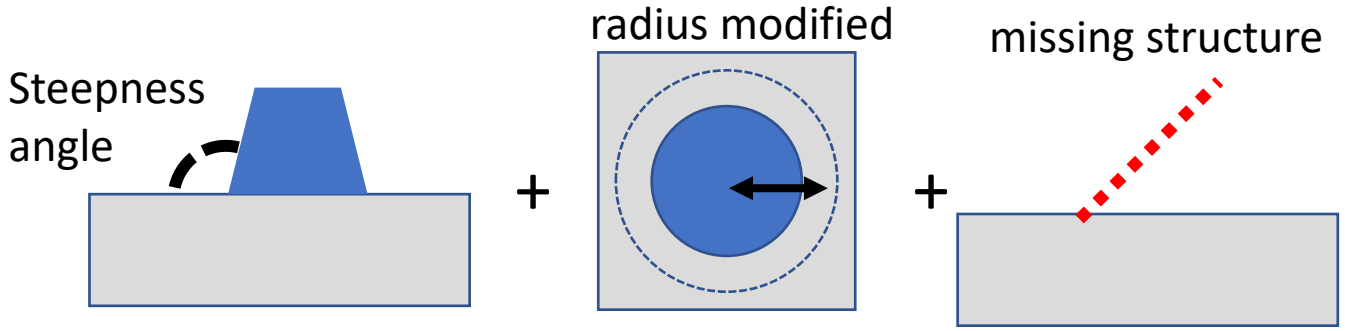
Time benchmark



# Robust Design : Yield and tolerancing example




- **Failure modes** and effects different from refractive lenses
- **Monte carlo** study for error **tolerancing**
- Sensitivity analysis reveals **critical** parameter and **thresholds**
- 25’230 metalenses simulated in this plot
- Component tolerancing should become linked to system tolerance

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